

Performance of AEA 80 Ah Battery under GEO Profile

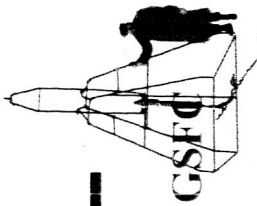
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(AEA Technology)

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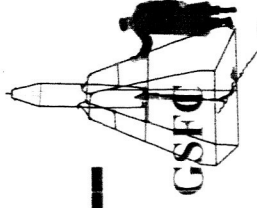
(NASA/GSFC)





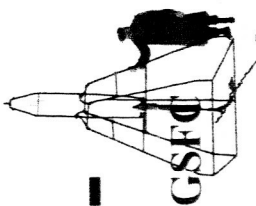
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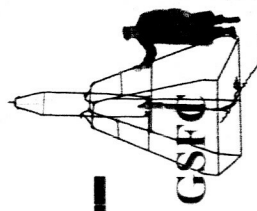
AEA GEO Life Testing

- AEA initiated cycling and calendar life tests over 6 years ago
 - Accelerated GEO cycling tests - no solstice period
- GSFC directed a real-time life test at battery level at AEA
- Battery design based on an existing module previously qualified for GSFC

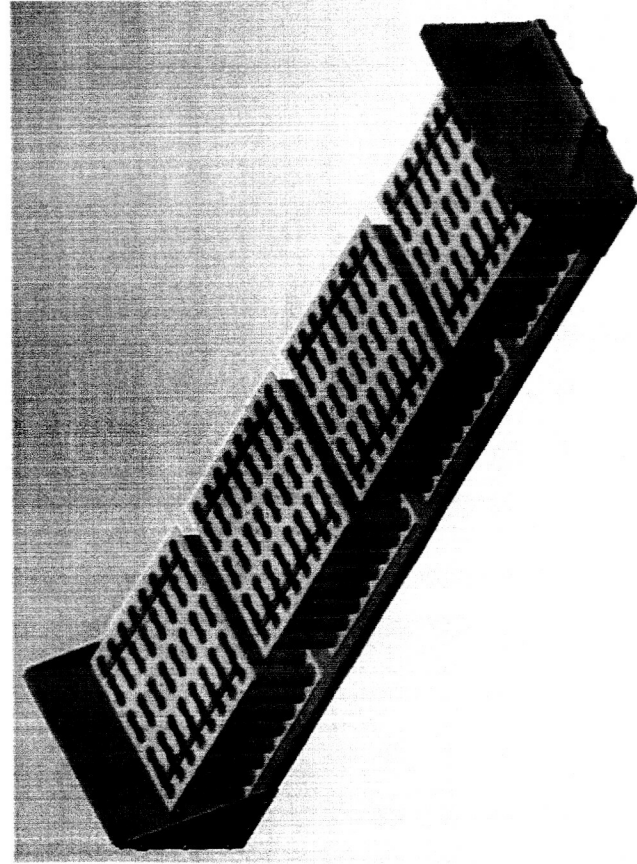


AEA/GSFC 20 Ah Battery

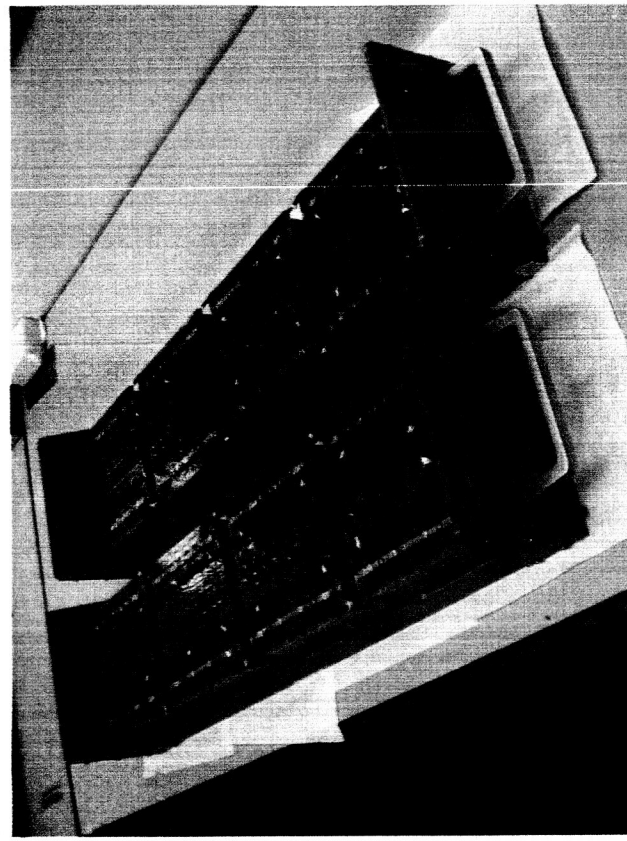
- Assembled using 128 individual SONY 18650 1.5 Ah cells
- Arranged in a S-P system topology
- 16 parallel strings each containing 8 cells in series
- 8 cells in series string provide battery voltage (20 to 33.6 V)
- Battery provides 20 Ah capacity when discharged at 10 A to 24 V at 20°C
- Six thermistors for temperature telemetry
- Three multi-pin connectors (Power, Flight Telemetry and Ground Telemetry)



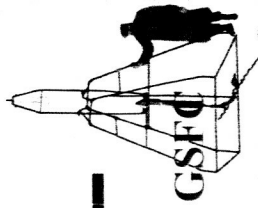
AEA/GSFC 80 Ah Battery



- 40 Ah Test module assembled using four of the standard 8 x 8 battery blocks
- Battery block uses qualified design from 20 Ah units



- Each block contains 64 cells
- Total of 256 cells per test module

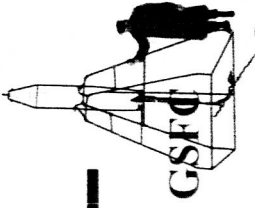


SDO Life Test: Overview

- Real time GEO life testing including solstice and eclipse seasons
- Battery at 32.3V voltage clamp during solstice
- Capacity measurements performed only at the start of each eclipse season
 - Before first eclipse season each year both AEA* and GSFC** capacity measurements performed
 - Before second eclipse season each year an extra AEA capacity measurement is performed

* C/10 charge to 33.6V and C/10 discharge to 20.0V

**C/10 charge to 33.6V clamp with a taper current to C/100 and C/2 discharge to 24.0V

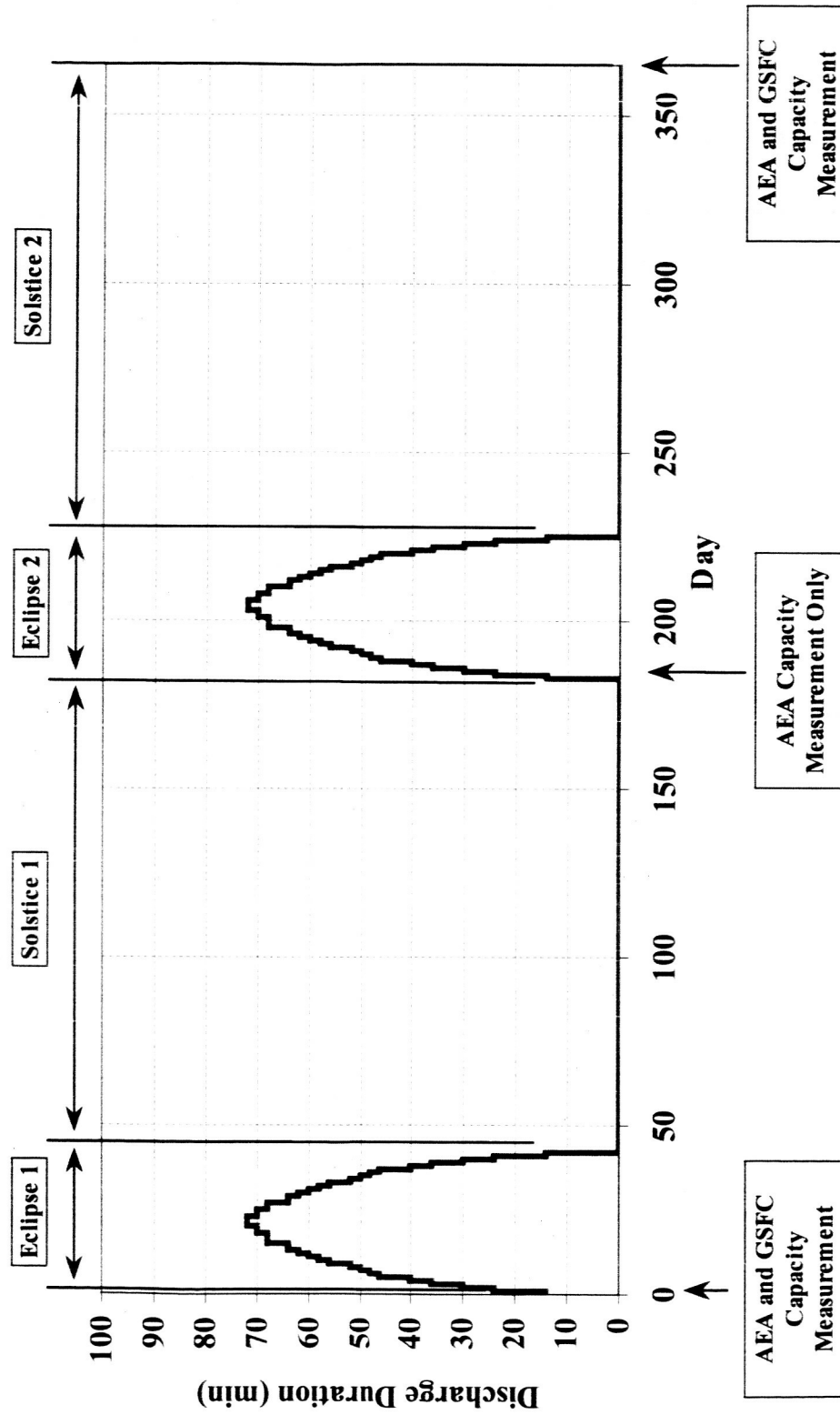
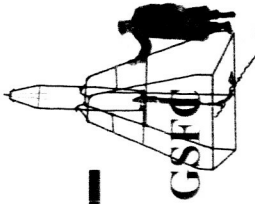


SDO Life Test: Overview – cont'd

- Eclipse Regime
 - Charge at 4A to 33.35V clamp with a taper to 0.1 A, followed by 0.1A constant current until end of the charge period
 - Maximum State-of-Charge (SOC) 98% day 1 and day 42
 - Minimum SOC 28% days 21-23
 - Discharge current 48A
- Solstice Regime
 - 140 days
 - Voltage clamp at 32.3V (72% SOC)
 - Fully charged before prior to commencement of eclipse season

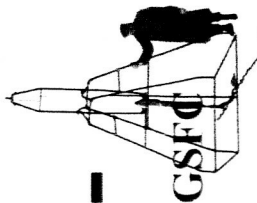


SDO Life Test: Real-Time Profile

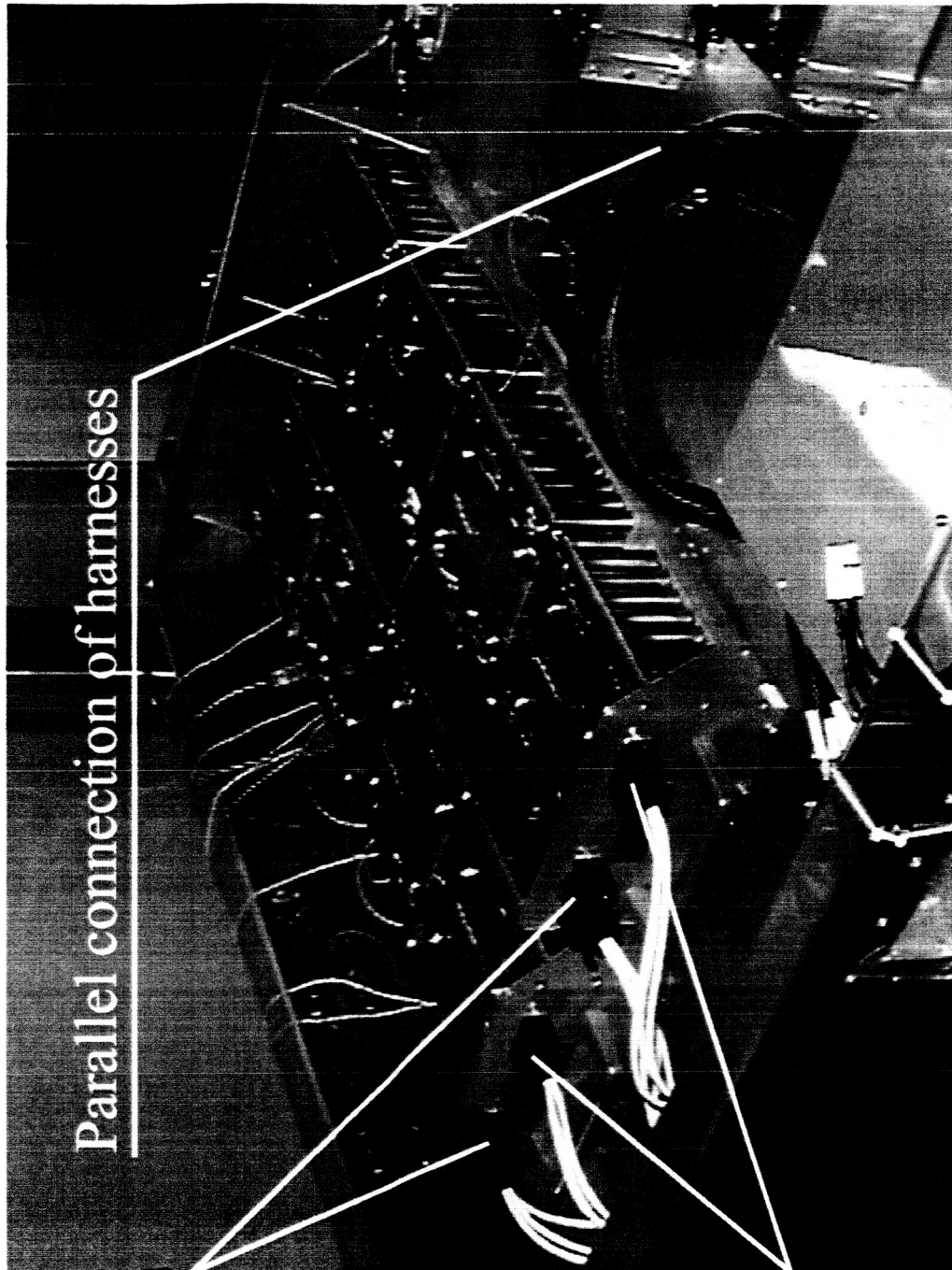




SDO Life Test Setup

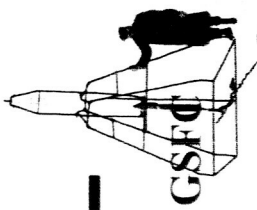


+ve connectors



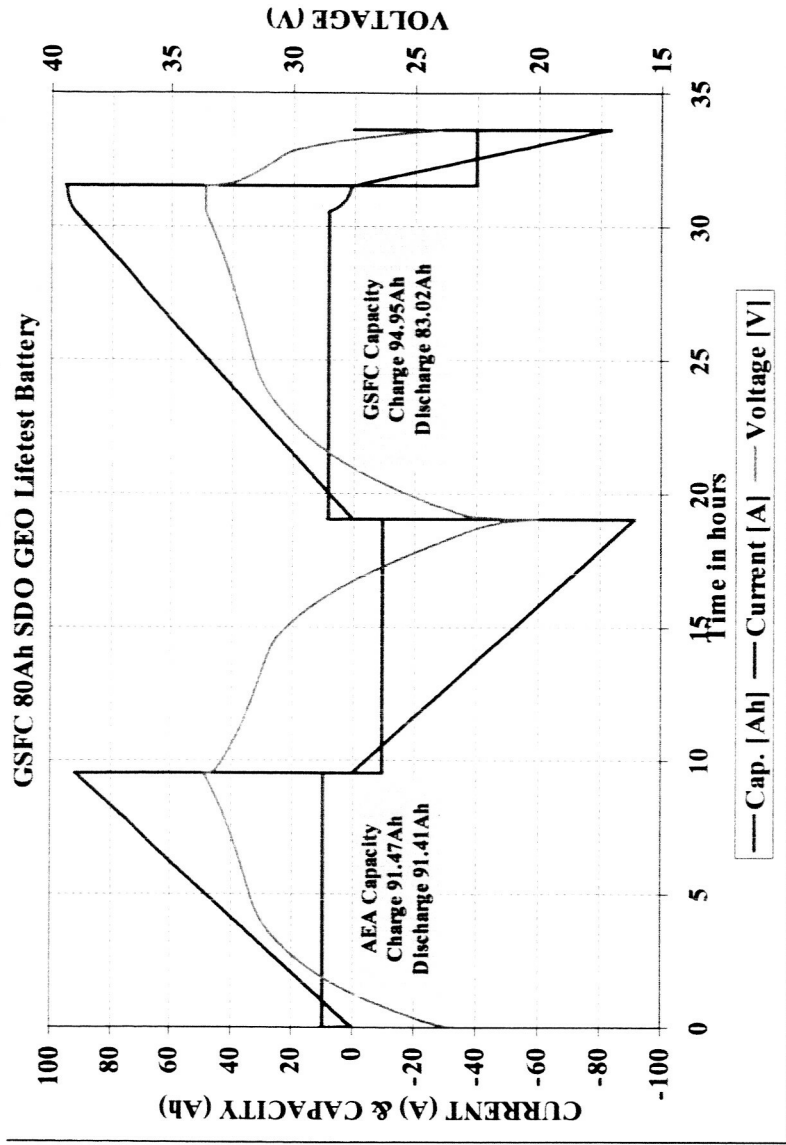
Parallel connection of harnesses

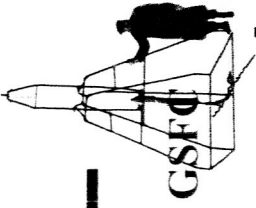
-ve connectors



Test Results

- AEA Standard Capacity Measurement (SCM) (C/10 charge and discharge) = 91.41 Ah
- $C_{TOTAL} = 97.76 \text{ Ah}$
- C_{GSFC} (C/10 charge & taper to C/100, C/2 discharge) = 83.02 Ah





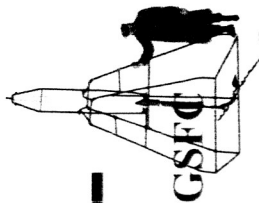
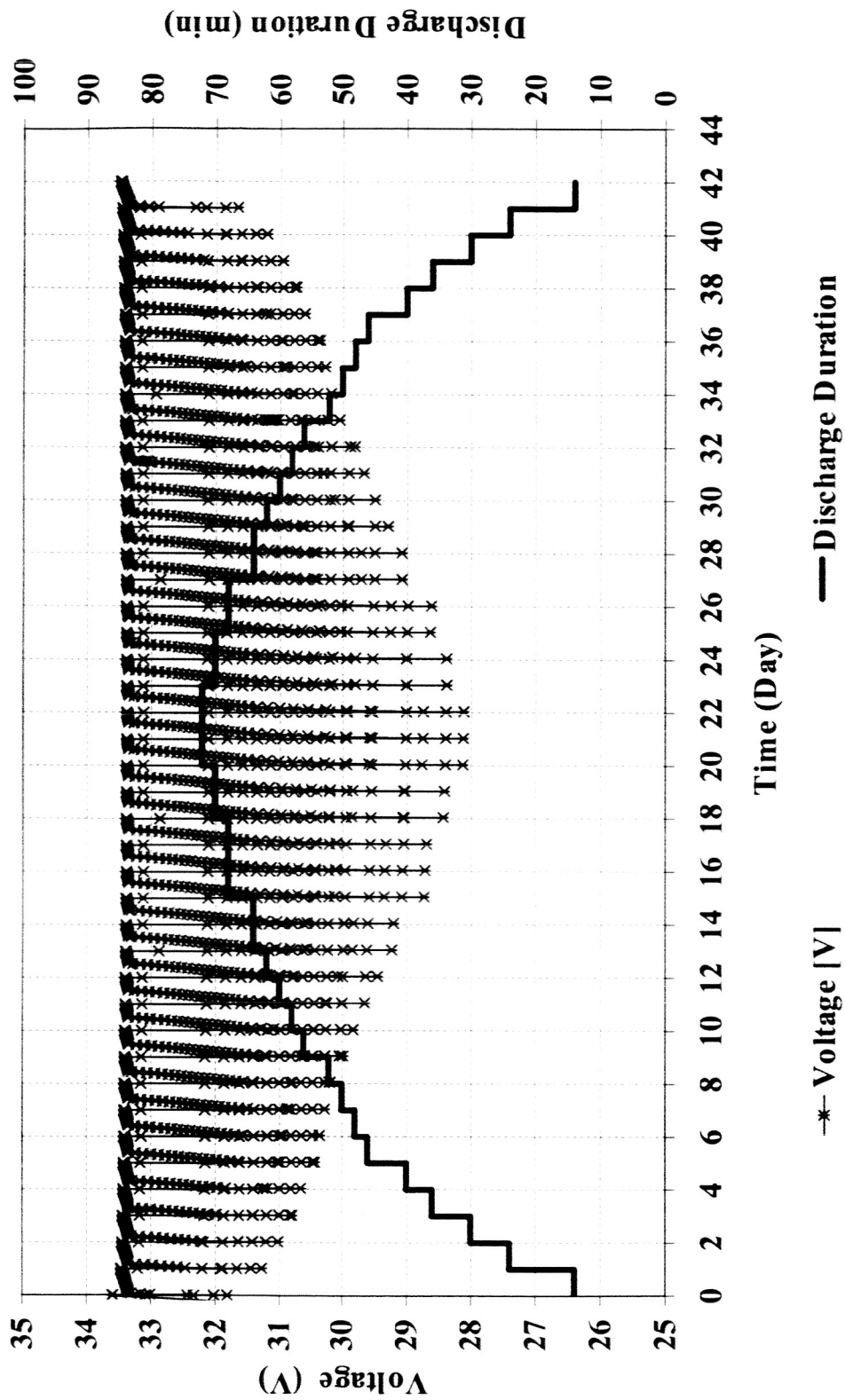
Test Results: Voltage

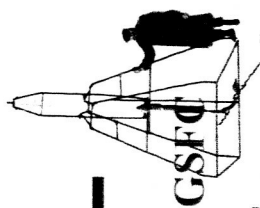
- Completed to date nominal three seasons
- Note rising voltage towards end of charge
 - True taper charge to very low current not possible with test equipment used
 - Min current without a specific 'rest' mode is 0.1 A
 - Therefore battery charged to 33.35 V then held at 0.1 A current for remaining duration
 - 33.35 V calculated to ensure battery remains below 33.6 V at end of charge for worst case (minimum discharge)



Test Results: Voltage

First Eclipse Season Profile

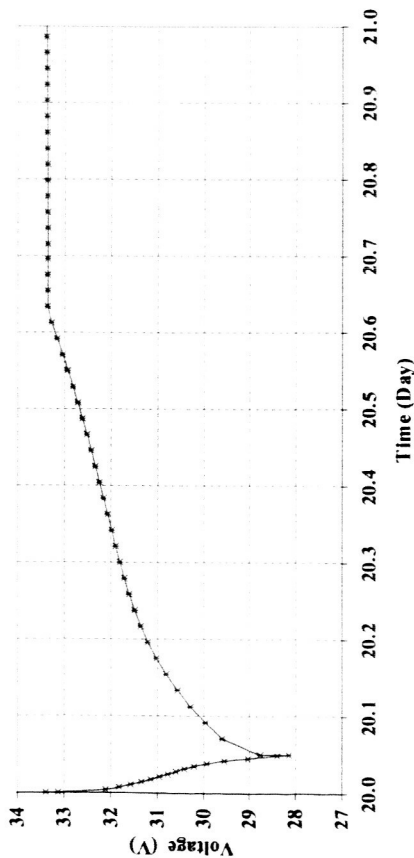




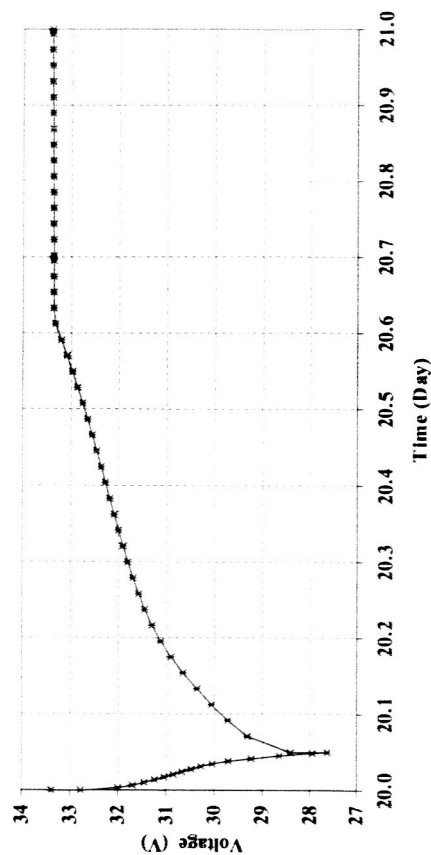
Test Results: Voltage

Profiles for Maximum Depth-of-Charge (DOD), 72%, for the Three Seasons

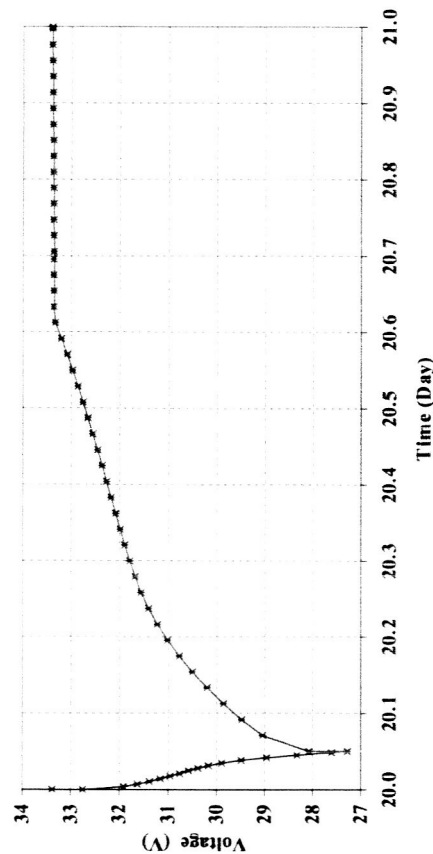
First Eclipse (72 min)

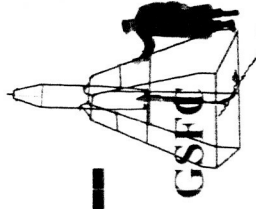


Second Eclipse (72 min)



Third Eclipse (72 min)





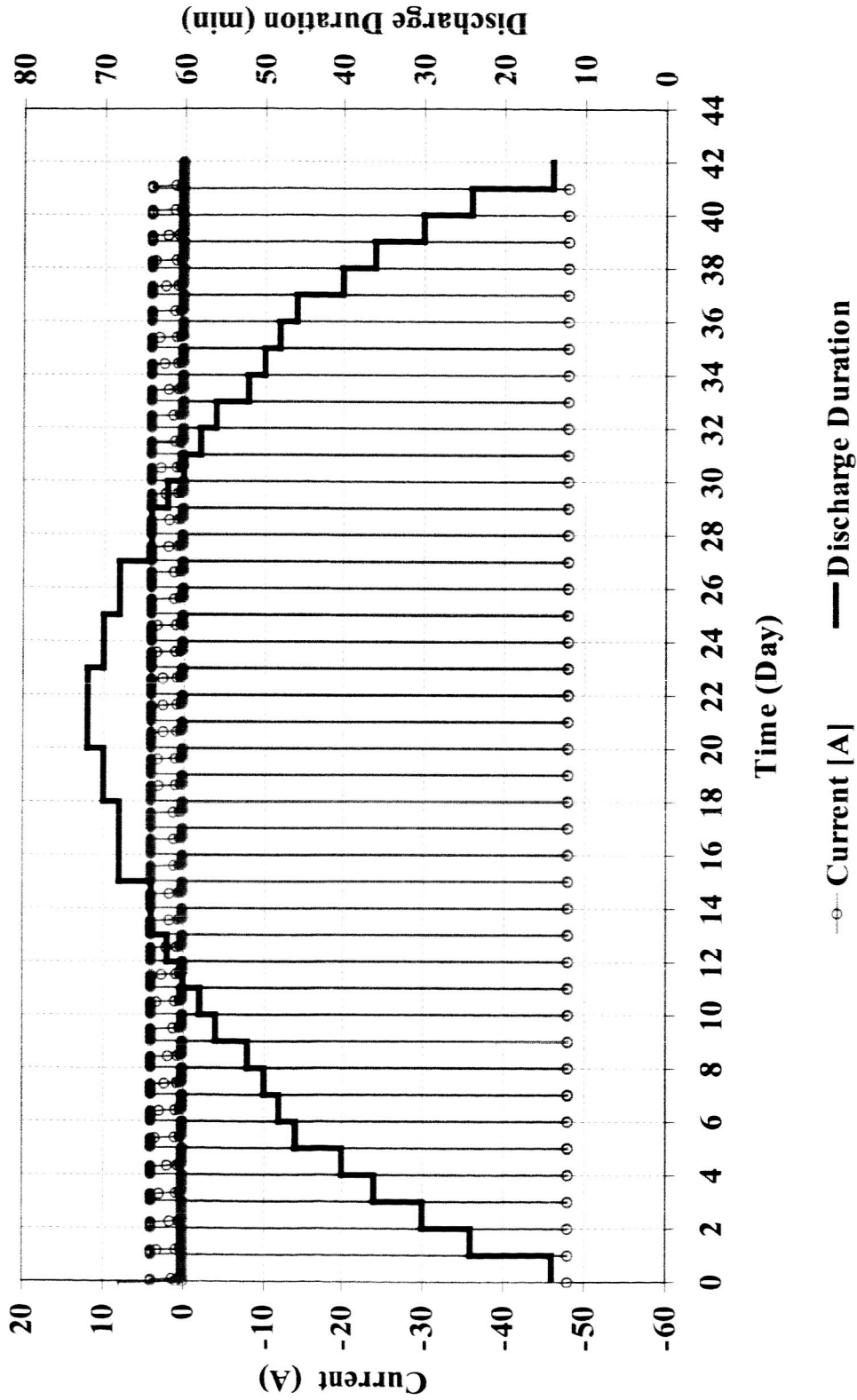
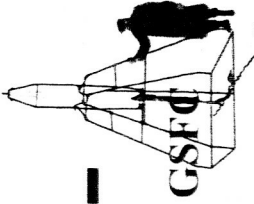
Test Results: Current

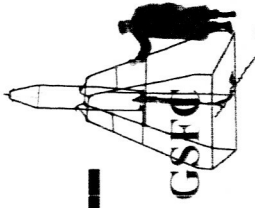
- Logged current shows three stages per orbit:
- Main constant current charge at 4 A
- Taper region when voltage clamped at 33.35 V
- Limiting 0.1 A current for remaining duration of charge
- 48 A discharge current results in peak of 57.6 Ah (equivalent to 72% DOD of C_{GSFC})



Test Results: Current

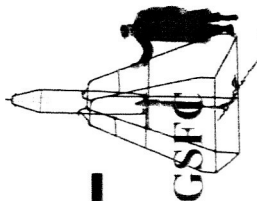
Profile for the Eclipse Season





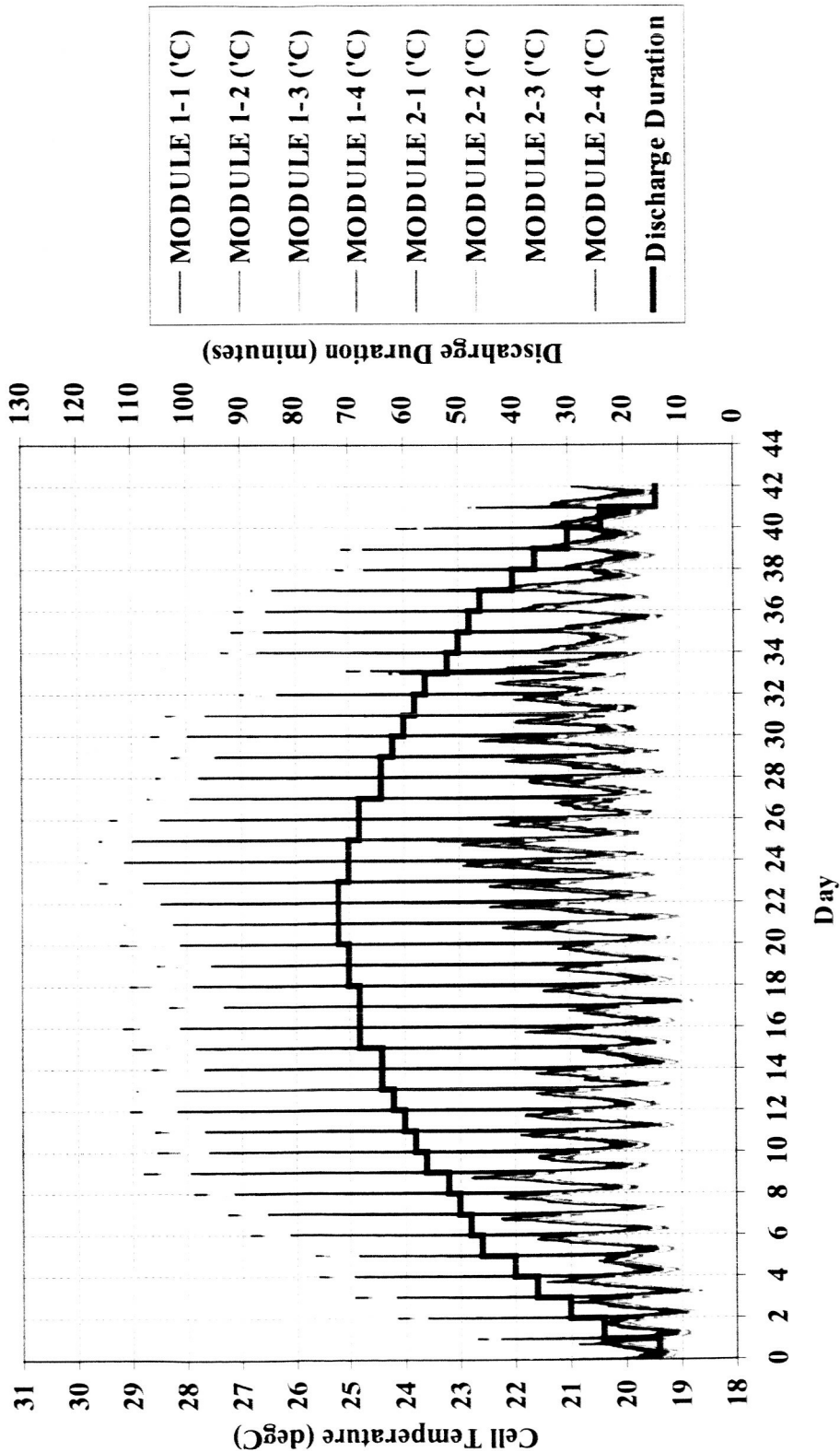
Test Results: Temperature

- 1 thermistor at the centre of each block
 - represents maximum cell temperature
- On following plot rapid 'spike' temperature rises during the discharge periods
 - Peak cell temperature approx 30°C
- Variation in temperature during charge follows repeating pattern:
 - Initially endothermic (temp falls below interface (I/F))
 - Then exothermic (temperature rises 1 to 2°C)
 - Then cells cool back towards I/F temperature near end of charge when current tapers and dissipation reduces
 - Small variation in I/F temperature due to thermal control limits
 - ~ 1 to 1.5°C



Test Results: Temperature

Profile for the Eclipse Season

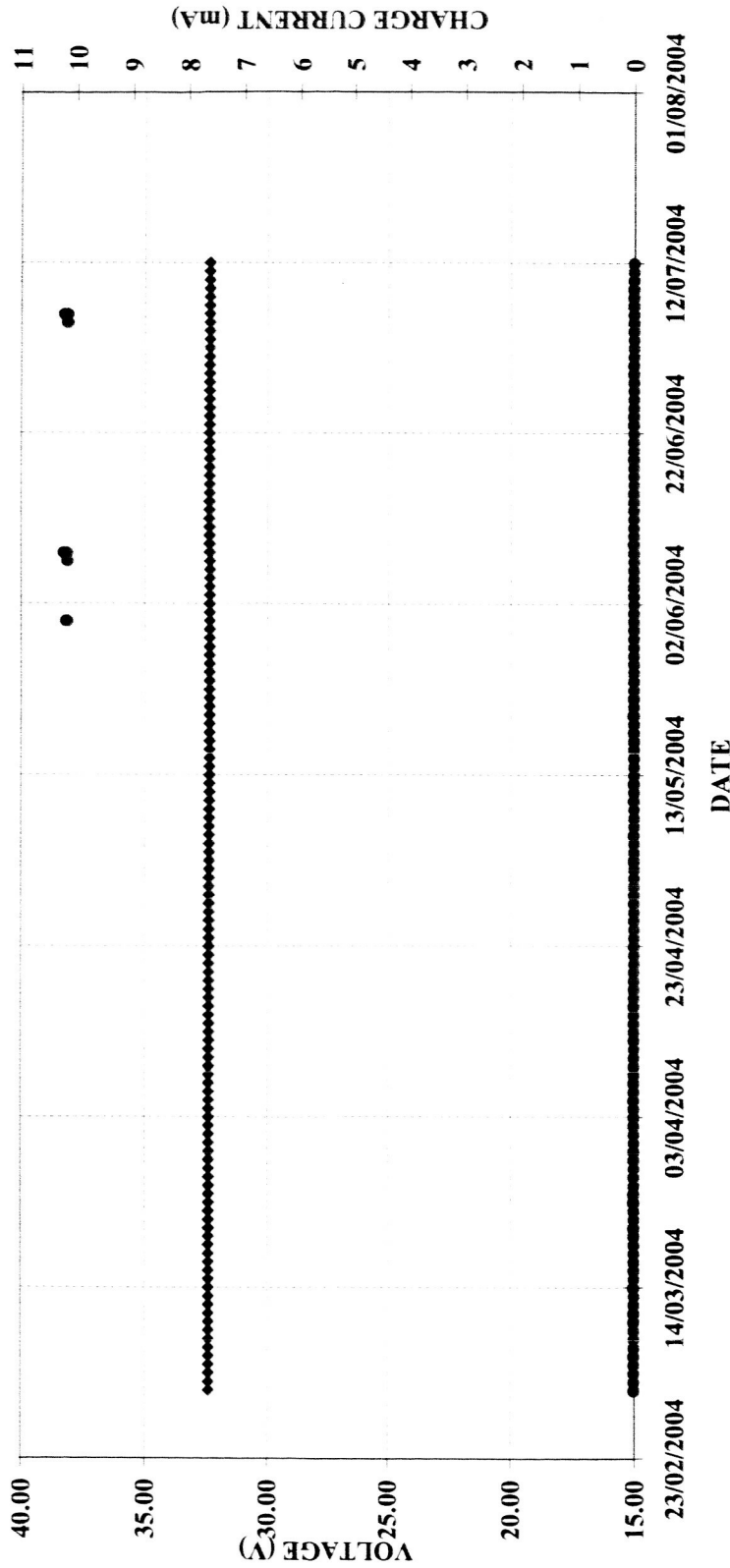




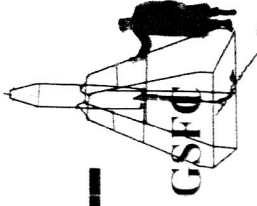
Test Results



GSFC GEO Battery Voltage and Charge Current 2nd solstice

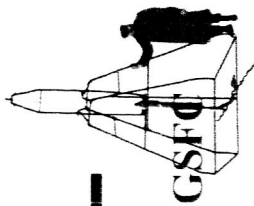


● Battery Voltage (V) ● Battery Current (mA)

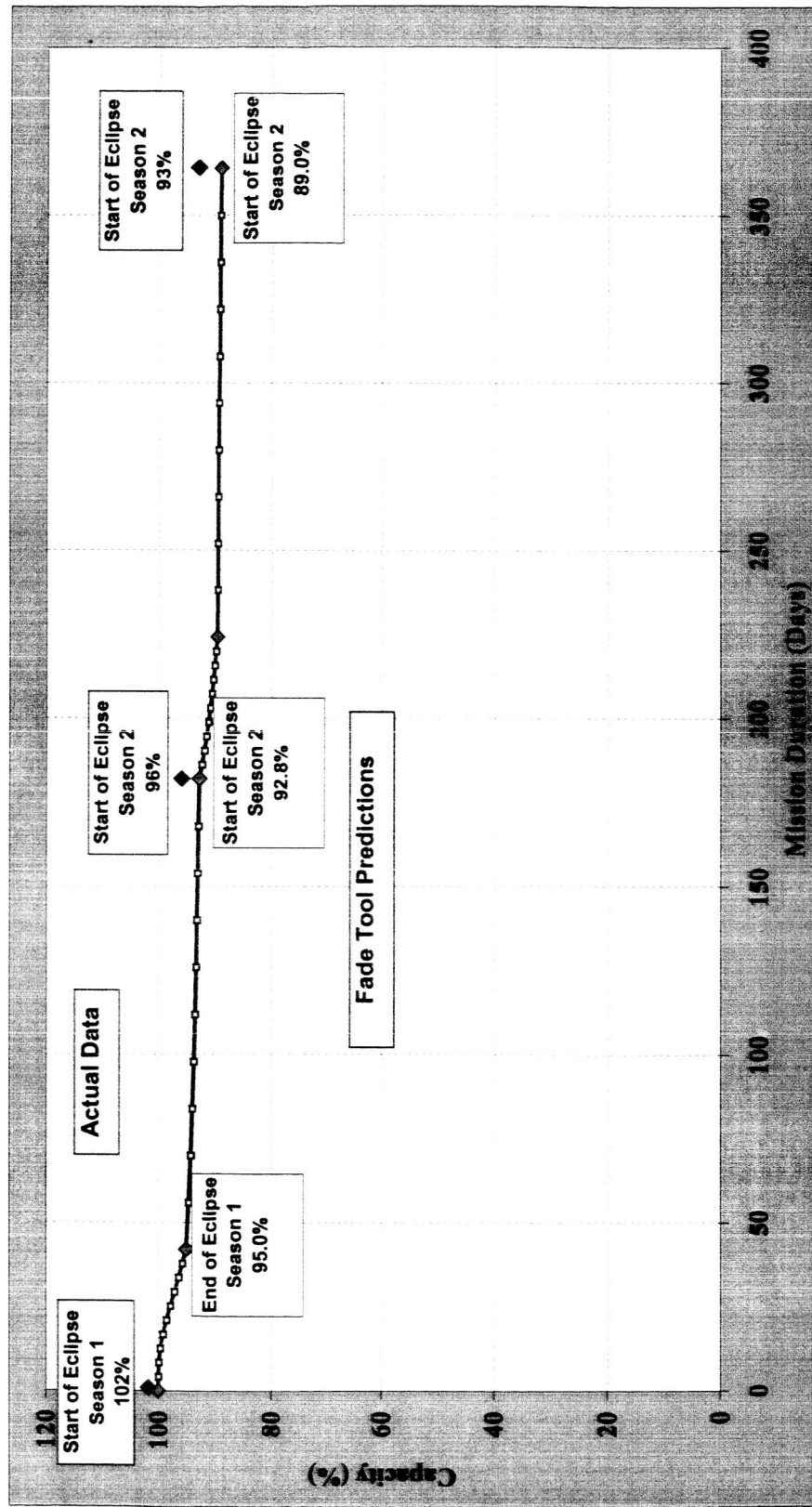


Correlation: AEA Fade Tool

- AEA life test program has accumulated over 40 million cell hours including 6 years calendar life
- Intended to simulate Low Earth Orbit (LEO), GEO, Middle Earth Orbit (MEO), Geosynchronous Transfer Orbit (GTO), Interplanetary and Planetary Lander scenarios
- Data has been incorporated into AEA fade tool

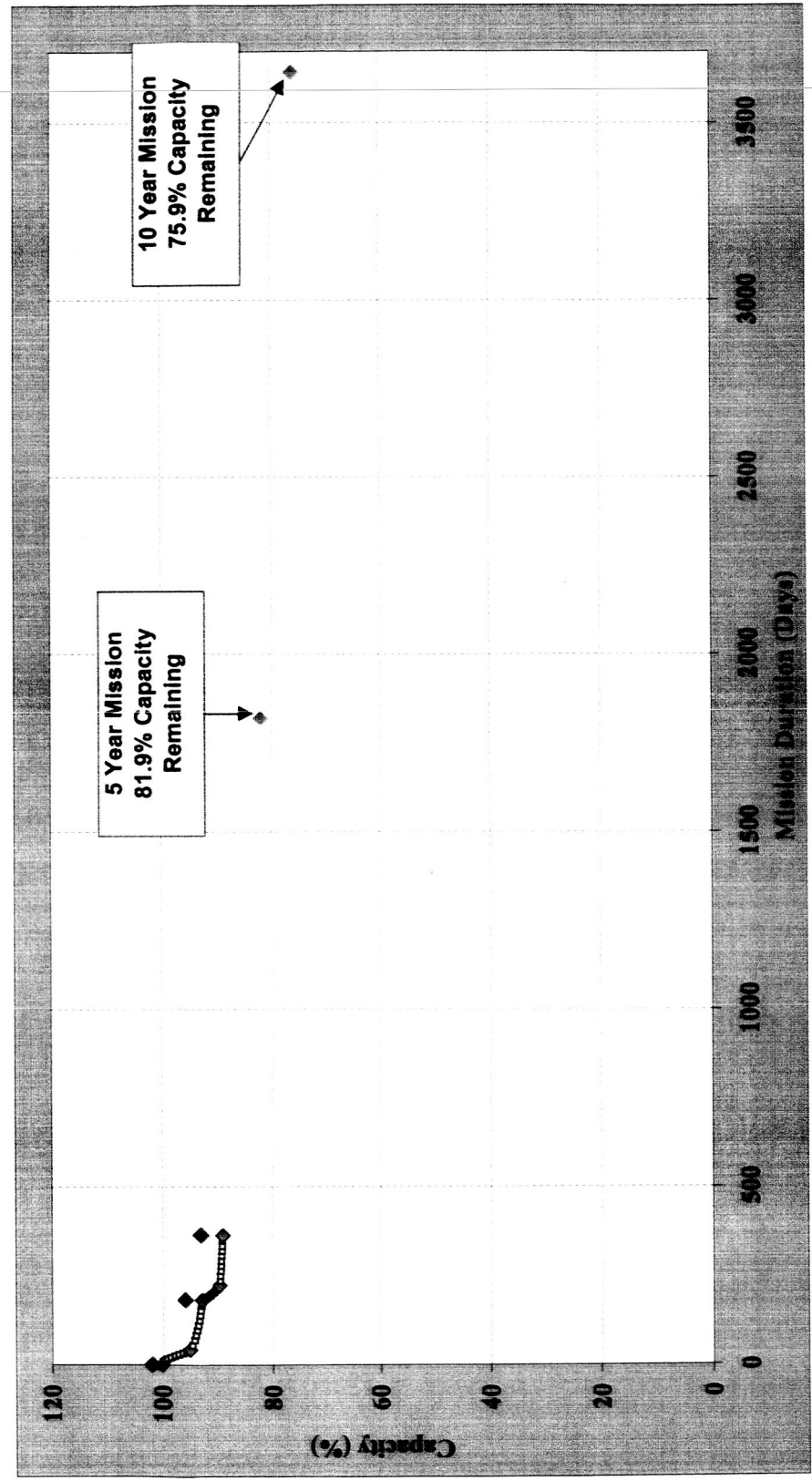
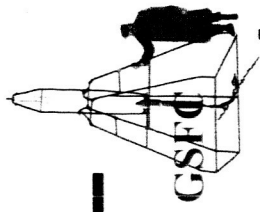


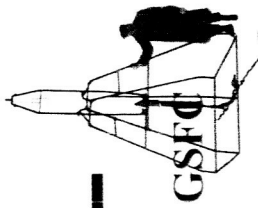
Correlation: AEA Fade Tool - cont'd





Correlation: Long Term Prediction





Conclusions

- Sony 18650HC has a low rate of capacity fade under GEO cycling regime
- Real time test results correlate with accelerated GEO lifetest data and AEA capacity fade prediction tool
- Completed to date nominal three SDO real-time eclipse seasons
- This data, together with other AEA test data, justify the SDO Project decision to baseline Lithium-Ion chemistry for the spacecraft battery.